Modelling and simulation of online partial discharge measurement for medium voltage power cable

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Article Info

ABSTRACT

This paper presents the modelling of the online partial discharge (PD) measurement of the medium voltage (MV) power cable. Recently, PD monitoring trends are rapidly increasing due to high demand on reliable systems. Degradation are mainly due to the presence of PD in the high voltage power equipment used. PD measurement is therefore a highly recommended task to early detection of the degradation insulation for high voltage (HV) equipment in order to avoid breakdowns. Real network modelling is necessary to improvise system design in order to find the efficiency in a real power system network. In this paper, modelling focuses on a real distribution network by applying Rogowski coil (RC) as a detection sensor to trigger PD activity. The simulation is performed to determine the functionality and reliability of the system with the RC application in the network. The analysis is performed in the ATP-EMTP and MATLAB Simulink software environments. In addition, this paper contributed to justify the approach of a simplified PD sensor and measurement system. This PD measurement system provides a complete solution in the context of condition-oriented monitoring for the ability to apply the RC to trigger PD activity in the power distribution network.

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1. INTRODUCTION

The condition monitoring system plays an important role in ensuring that the electrical supply network operates efficiently. The electrical supply worldwide runs simultaneously at 24 hours and 7 days a week, particularly on the side of MV. As a result, various components of MV electrical power face environmental stress [1]. Condition-based monitoring of the power system needs the best part and equipment infrastructure that is reliable when efficient maintenance is performed [2]. Early information on possible breakdowns in online mode is considered to be crucial, particularly for PD in HV equipment [3-4]. As a result, utility providers continue to strive to find ways to increase the efficiency of the electricity supply's continuity [5-7].

One of the key components is the MV underground power cable for distribution networks. This element is usually subjected to stress, including electrical, thermal, mechanical and environmental stress, which contributes significantly to the deterioration of its insulation [8-9]. Degradation insulation in MV underground cable is highly proven by PD activities [3]. PD is a localized discharge that only partially

bridges the insulation between the conductor and may or may not occur adjacent to the conductor [10]. The high precision of the PD measurement system is essential for capturing PD activity as it occurs in the short duration of current pulses, usually for only a few nanoseconds [11-13, 14]. PD usually occurs before the breakdown indicates that PD monitoring can be a good system to install, with reference to data from [15]. The data collected through the PD monitoring system can also keep the insulation system stable in real-time. It is therefore possible to improve reliability, performance, equipment security and costs. The traditional method is to use off-line measurement where the routine is disrupted. It will be more economical to inspect the equipment without interrupting the whole system. Online PD assessment is the best way to ensure the optimum quality of PD analysis [2,7,16,17]. The standard PD measurement refers to IEC 60270 [18], which provided a complete measure requirement. The main advantage of the PD measurement is the early detection of PD activity, which can prevent the equipment from breaking down [19–21].

At present, the traditional PD sensors are saturated, tremendous, bulky, low sensitivity, and high cost compared to Rogowski coils (RC), such as High-Frequency Current Transformer (HFCT) and Coupling Capacitor (CC)[22]. The PD behavior will be measured by the current pulse when the RC is clamped around the supply cable [6, 23]. Whereas online measurements also have drawbacks, such as the need to collect data manually and take an enormous amount of time and human power [24-25]. Over the last few years, PD measurement has attracted increasing attention due to the high efficiency and reliability of the system[26-27]. In this paper, therefore, the modelling and simulation of online PD measurements for medium voltage power cables in order to identify the capability of the RC sensor performed in a real network has been successful with the significant PD waveform. The apparent conversion of the charge was also introduced, indicating a good result of the simulation. It is therefore clear that the RC sensor developed is suitable for use on-site with high advantages for the user.

2.   RESEARCH METHOD

Although realistic findings from PD measurements and test samples are the main source for research and analysis of the PD phenomenon, modelling and simulation often play an important role in PD studies. A reliable PD model can save time for realistic experiments that can be performed over hours or days and can predict insulation life without repetitive, long term tests. This modelling system is developed by reference to the standard IEC 60270. The RC [28] is used as a modelling measurement sensor. Figure 1(a) shows the complete model of a 70 km power distribution network using the J-Marti model, and Figure 1(b) shows the three phase RC model using the EMTP-ATP software. The network consists of a 33 kV power source, a 33/11 kV step-down transformer, a 300 mm2 XLPE underground cables and loads. The network is designed on the basis of a real network to justify the ability of the RC sensor to detect PD activity.
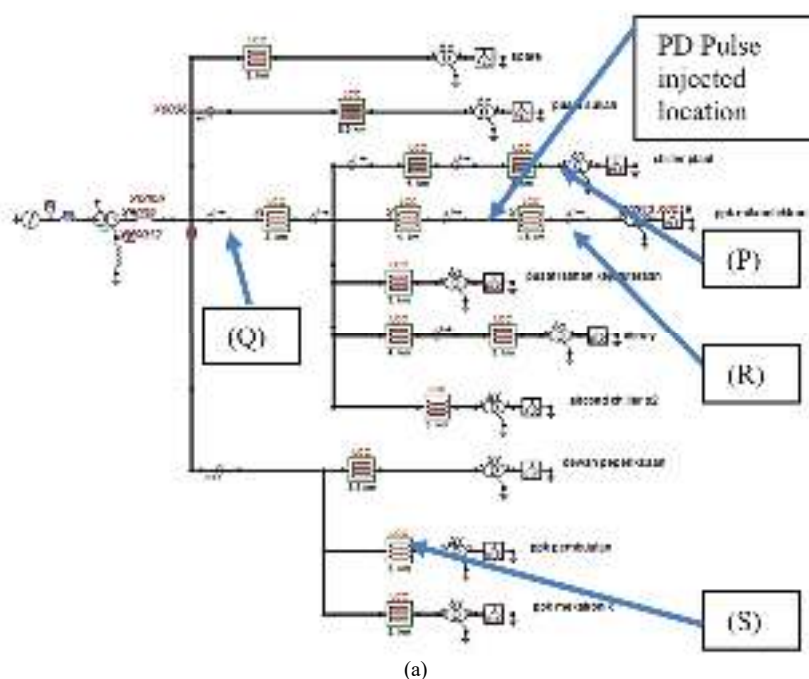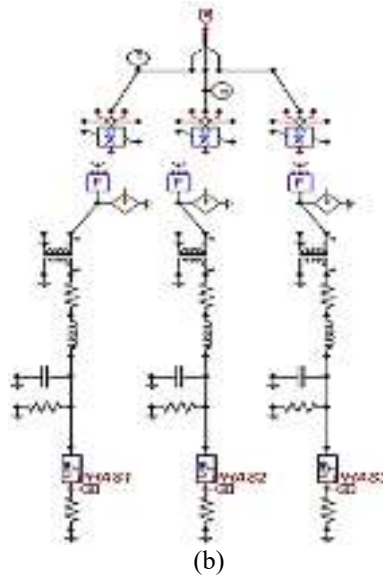

(a)

Figure 1. (a) Model of 70 km of real power distribution network using EMTP-ATP

(b)

Figure 1. (b) Model of Rogowski coil for a three-phase system (*continue*)

The RC sensor model, as shown in Figure 1(b), has a very large frequency response and there is no conductive coupling between the coil sensors and the test element. Furthermore, the installation of the coil does not require the grounding leads of the test items to be disconnected and thus becomes a non-intrusive sensor which is very useful for on-site measurement online. The PD pulse model, as shown in Figure 2, was designed on the basis of the specific parameters indicated in Table 1 and used in the Fortran expressions by the implemented equation (1). The simulation is then communicated to the feeder as a TACS-controlled current source type 60 to generate multiple PD pulse [28]. The PD pulse is injected into the network at leg four as shown in Figure 1(a), while the RC model is connected to the points P (11 km), Q (7 km), R (1.5 km) and S (15.5 km) from the PD pulse to find the output trigger.

$$i(t) = A[10^{-1.3\frac{(t-t_0)}{\tau}} - 10^{-\frac{2.2(t-t_0)}{\tau}}] \tag{1}$$

Where: A is the amplitude of the PD pulse
          t_o is the time of PD occurrence
          τ is the damping factor of the PD pulse

Table 1. Parameter PD pulse

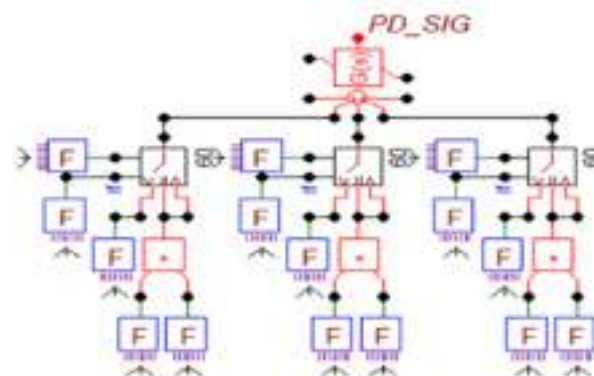| No	A(mA)	$t_o(\mu s)$	$\tau(\mu s)$
1	14.83	30	0.08
2	13.50	60	0.08
3	12.75	90	0.08

Figure 2. The model of PD pulse

2.1. Apparent charge conversion

The captured PD data is primarily an oscillatory voltage pulse that needs to be processed in order to obtain PD characteristics such as peak value, apparent charge, phase position, repeat rate, and PD energy. The apparent charge $q(t)$ enters into the system due to PDs is given as:

$$q(t) = \int i(t)dt = -\frac{1}{M} \iint Vout(t)dt^2 \qquad (2)$$

Where: *Vout(t)* is the oscillating voltage appearing at the output terminals of the sensor

M is the mutual inductance of the RC, which is taken as 200 nH in this work

i(t) is the current flowing in the conductor due to PDs

IEC 60270 and IEEE standard states that the standard unit for measuring PD signal uses an apparent charge instead of voltage[29]. Regular modeling and measurement only produce output in mV unit. It is therefore necessary to convert to a charging unit. Using the above steps and the mathematical expression of the equation (2), the following Simulink model was modelled, as shown in Figure 3, to measure the PD magnitude of the load unit by the RC. The input (data3) is taken from simulation results in previous work, as mention in modelling of the measurement, and from the integral process performed to obtain the charging part. The filtering process uses a Butterworth type referring to the suggestion of previous researchers [30]. The mutual inductance of the coil is independent of its position around the cable [30]. The constant value of *M* (200 nH) is therefore used for calculations and modelling.
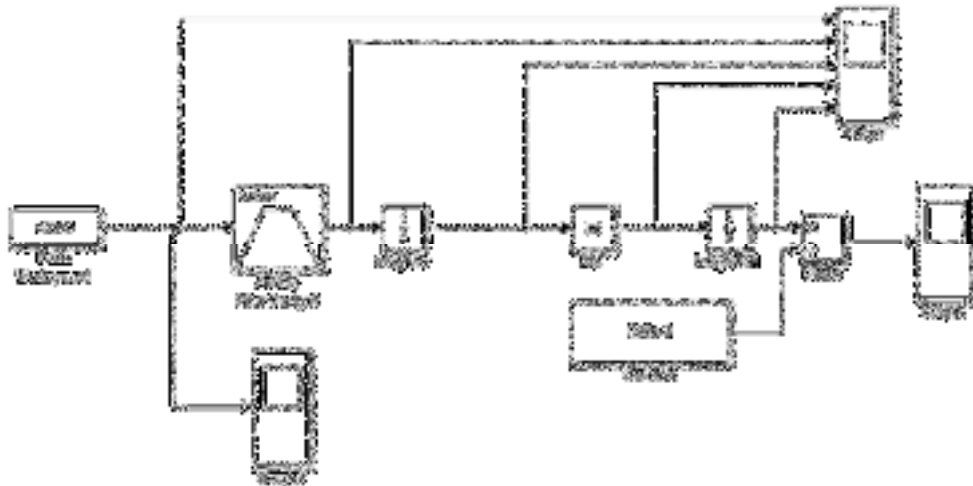

Figure 3. modelling for PD measurement in charge unit using MATLAB simulink

3.   SIMULATION RESULTS

Simulation is performed in EMTP-ATP and MATLAB Simulink for both measurement and conversion. The model was run several times at each location of the RC used, and the highest and stable values were taken into account. It was set to inject the PD pulse with 3.2 V, as shown in Figure 4 into the network location, and was repeated at least 3 times at each detected location to ensure that a correct PD pattern was captured.
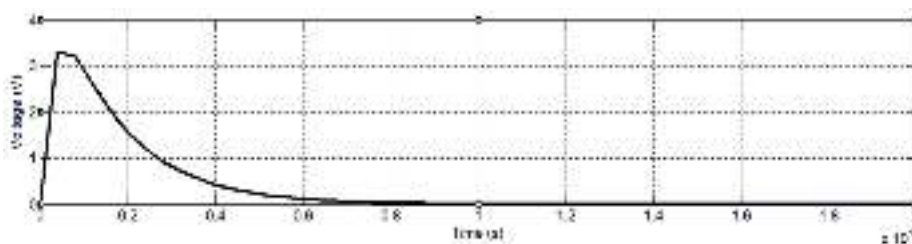

Figure 4. Output for the PD pulse model

As a result, the PD signal is present at all measured locations P, Q, R and S with significant value, which is capable of clarifying the quality and distance of the PD detected from the PD source. The result shows the amplitude of the PD signal detected in the time domain while the result of the Fast Fourier Transform (FFT) is the frequency response on the PD signal. The simulation results of PD measurements are shown in Figures 5-8 and summarised in Table 2. It is shown that the PD signal is detected at the highest amplitude of 13.13 mV and 0.0127 in FFT at location R, as shown in Figure 5. This means that the PD signal detected is closest to the PD source. While the amplitude value at location S is the lowest in Figure 8 with only 0.5442 mV, since the RC distance from the PD source is very far (15.5 km) compared to location P (7 km) with 1.089 mV and location Q (11 km) with 1.089 mV. The FFT result represents the frequency response of the RC to the PD signal. Most of FFT result shows in range more than 10 MHz fulfil the standard PD characteristic. This result can lead to the conclusion that RC sensors can be used in real networks capable of showing very significant trigger value, and that data can also be used to determine the exact location of the PD.
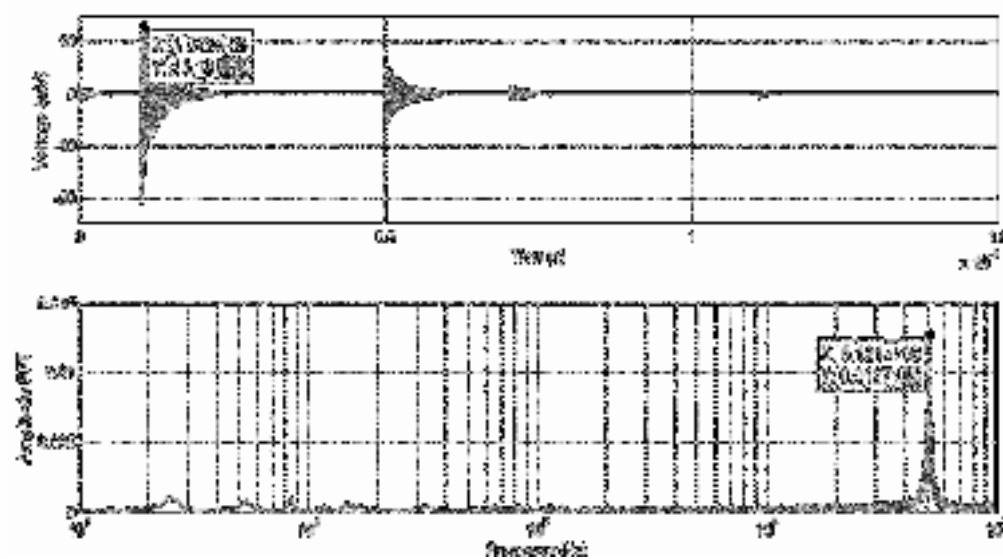

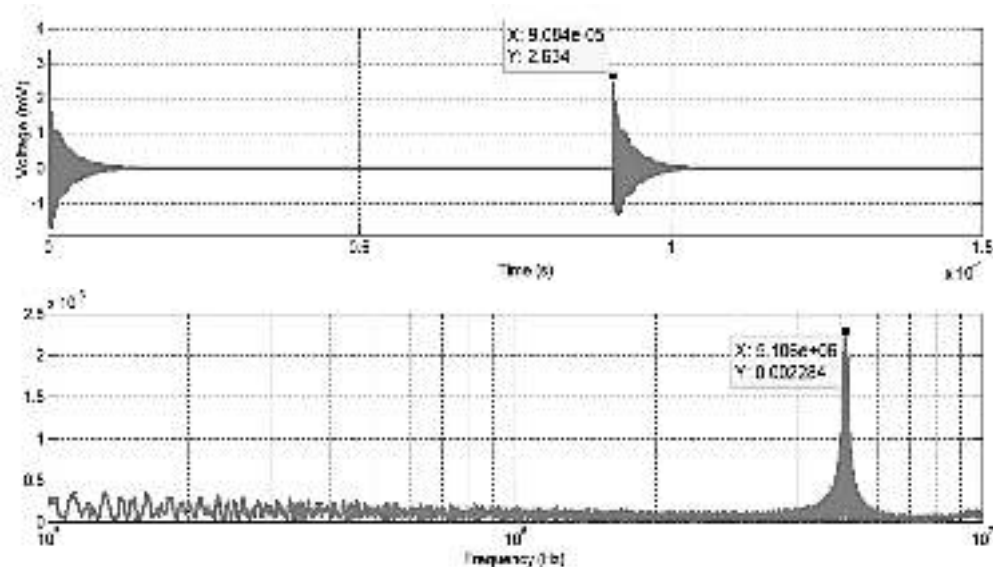Figure 5. PD signal in time and frequency domain detected at point R (1.5 km)

Figure 6. PD signal in time and frequency domain detected at point Q (11 km)
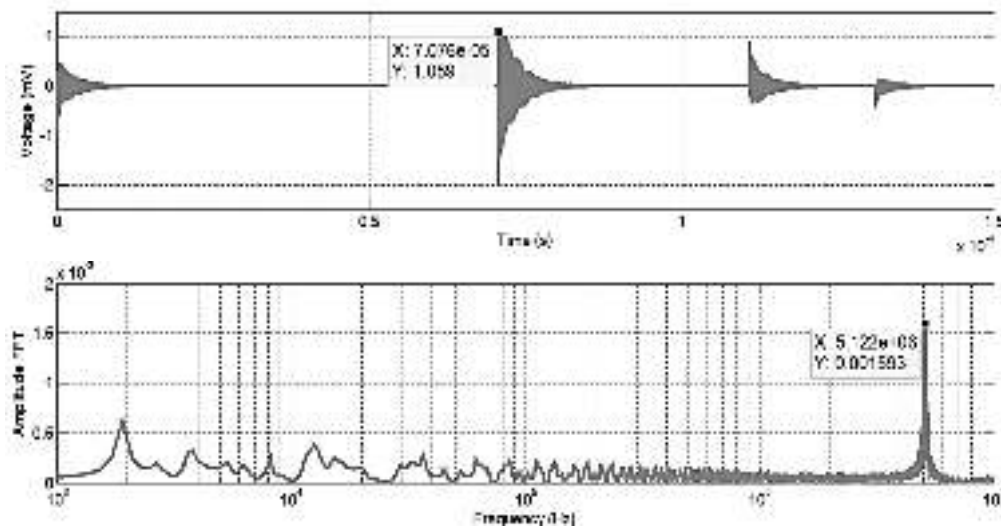
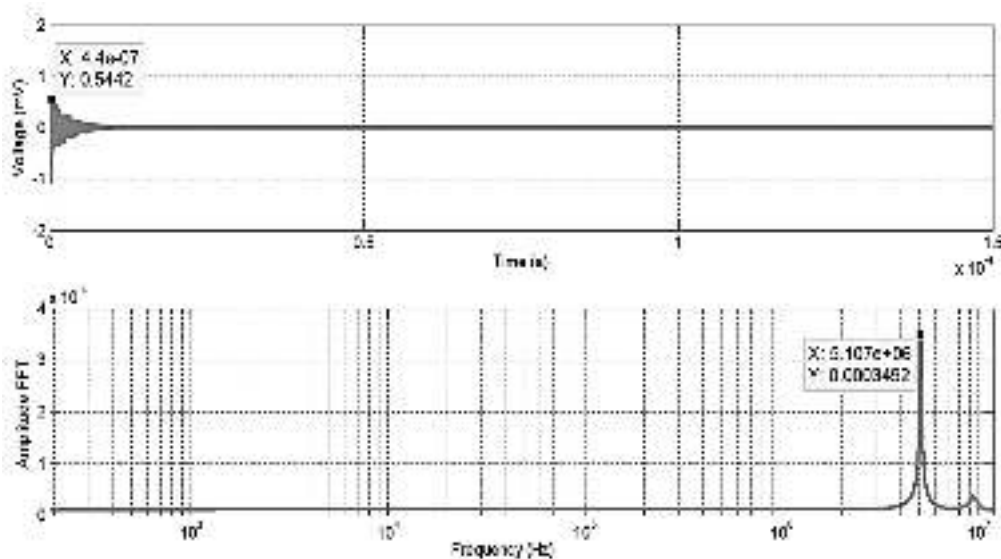Figure 7. PD signal in time and frequency domain detected at point P (7 km)

Figure 8. PD signal in time and frequency domain detected at point S (15.5 km)

Table 2. Result of Simulations

Location	Distance	Amplitude (mV)	Amplitude FFT
P	11 km	1.089	0.001593
Q	7 km	2.634	0.002284
R	1.5 km	13.13	0.01271
S	15.5 km	0.5442	0.0003492

The step-by-step conversion of the apparent PD load measured using the MATLAB Simulink model is shown in Figure 9. The input data Figure 9 (a) in the mV value is imported from the measurement data to the model in Figure 3. Then filtering process using the Butterworth type is used at the next stage in Figure 9 (b) to eliminate noise. Two stages of integral are used to define the average value of the PD signal as shown in Figures 9 (c) and (d). Finally, the significant charging unit set out in Figure 9 (e) represents the charging unit in Pico Coulomb (pC) that meets the requirements of this work. The last value of the apparent charge in the measured cable is about 2500 pC, indicating the high enough of the discharge activity. From this, the correct PD signal can be identified or the noise signal has been detected.
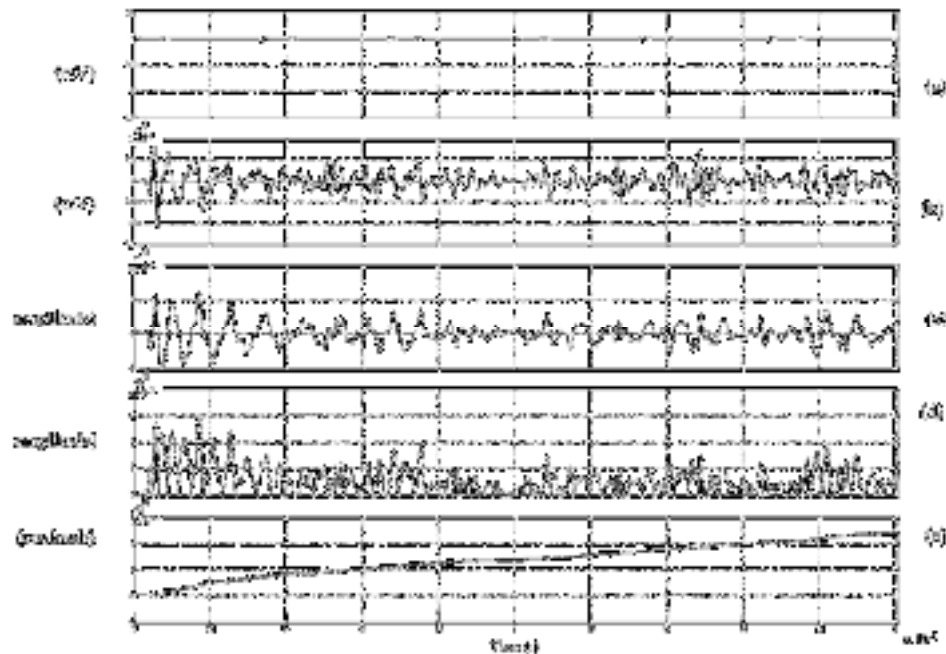
Figure 9. Apparent charges of PD measurements using MATLAB Simulink, (a) Input data in mV,
(b) After filtering, (c) After first integral, (d) After second integral, (e) Apparent charge output

4.   CONCLUSION

This paper presents the modelling and simulation of the online partial discharge (PD) measurement of the medium voltage (MV) power cable. The objective of checking the ability of RC to detect PD activity in a real distribution network has been successfully archived. The model of the RC sensors, the PD pulse and the actual 70 km network function properly during simulation produces a clear and significant result. It shows that the PD signal in the power cable modelled along the network can be triggered by the result of the RC sensor. The PD amplitude detected was at the highest of 13.13 mV and the lowest at 0.54 mV, depending on the location of the RC and the PD pulse. It was clearly indicated that the nearest RC to the PD pulse would produce the highest amplitude and frequency response. Finally, the modelling of PD measurement can be further improved and explore since it gave a significant result. Finally, the modelling of the PD measurement can be further improved and explored as it has yielded significant results. This will make the actual measurement easier to perform and will help improve the ability to detect PD in the medium voltage power cable.

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